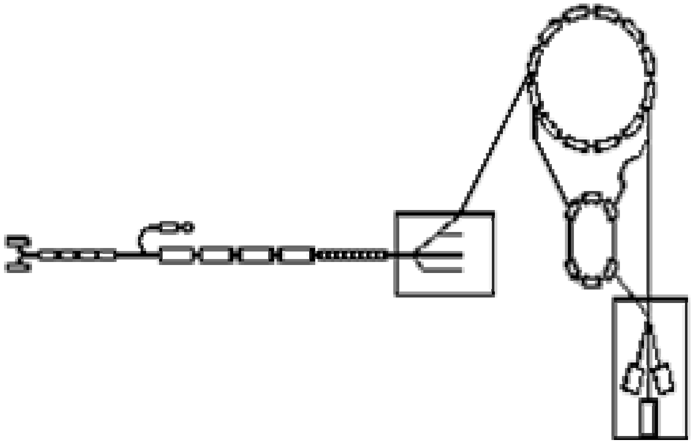
Beam Intensity Losses Due to Intra-Beam Collisions

Harald Bräuning

Institut für Kernphysik, Strahlenzentrum
Justus-Liebig Universität Giessen

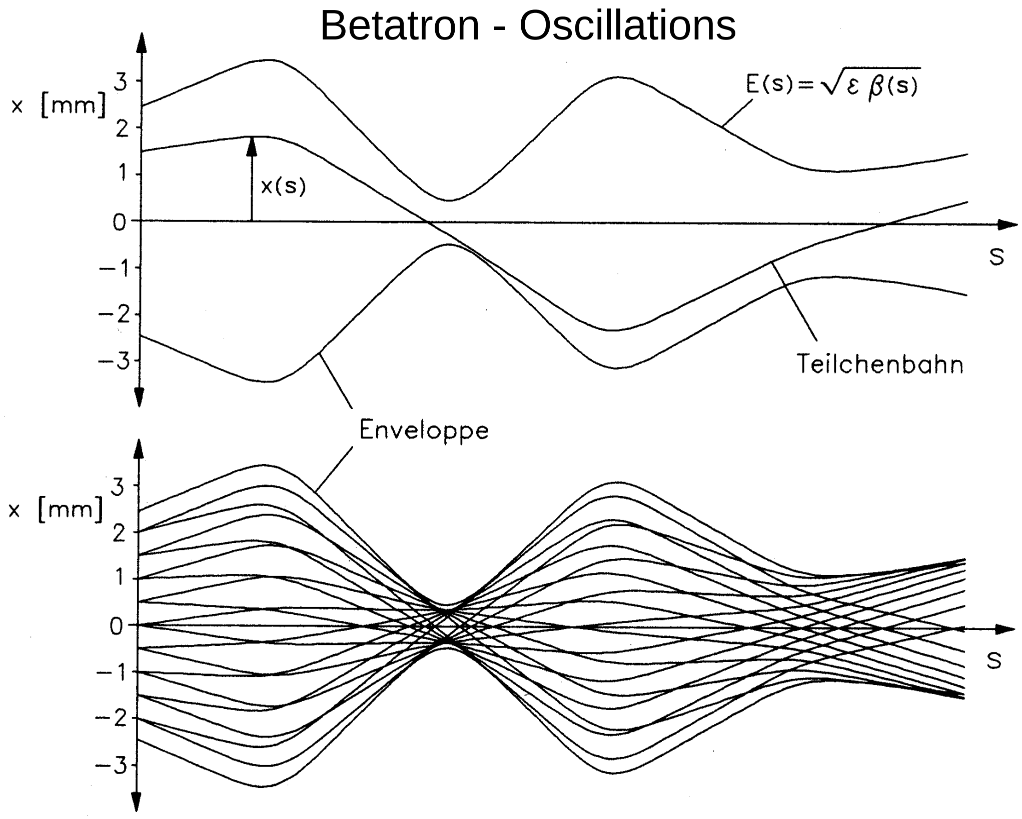
Future: acceleration and storage of intense ion beams



i.e. plasmaphysics:

- interaction of heavy ions with a plasma
- generation of very high energy densities in matter

Intra-Beam Collisions



element :	Xe
energy E_{kin} :	400 MeV/u
radius R :	172 m
betatron tune Q :	15.9
emittance ε_{rms} :	14 mm mrad

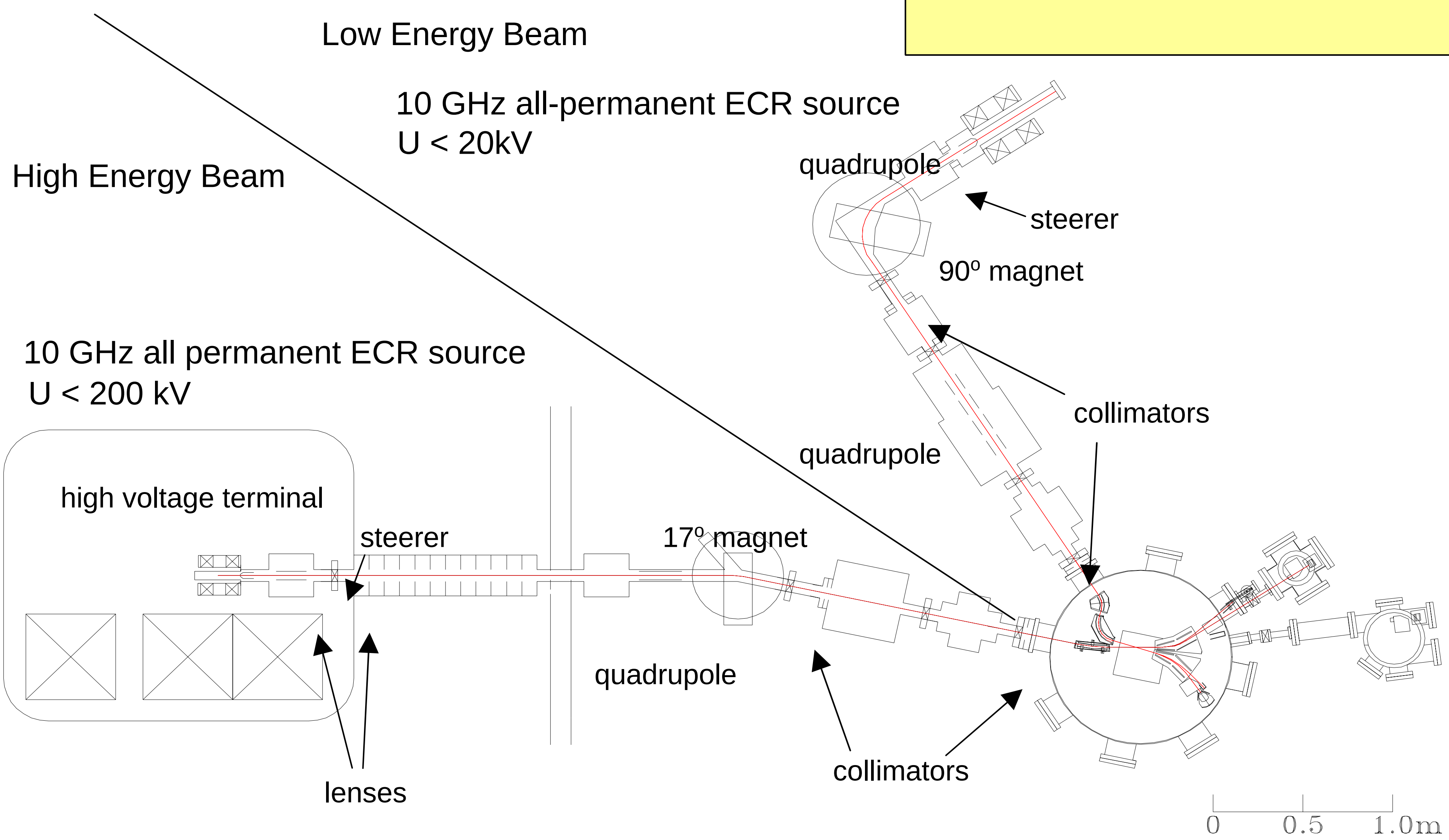
E_{trans} = 125 keV

reaction rate:

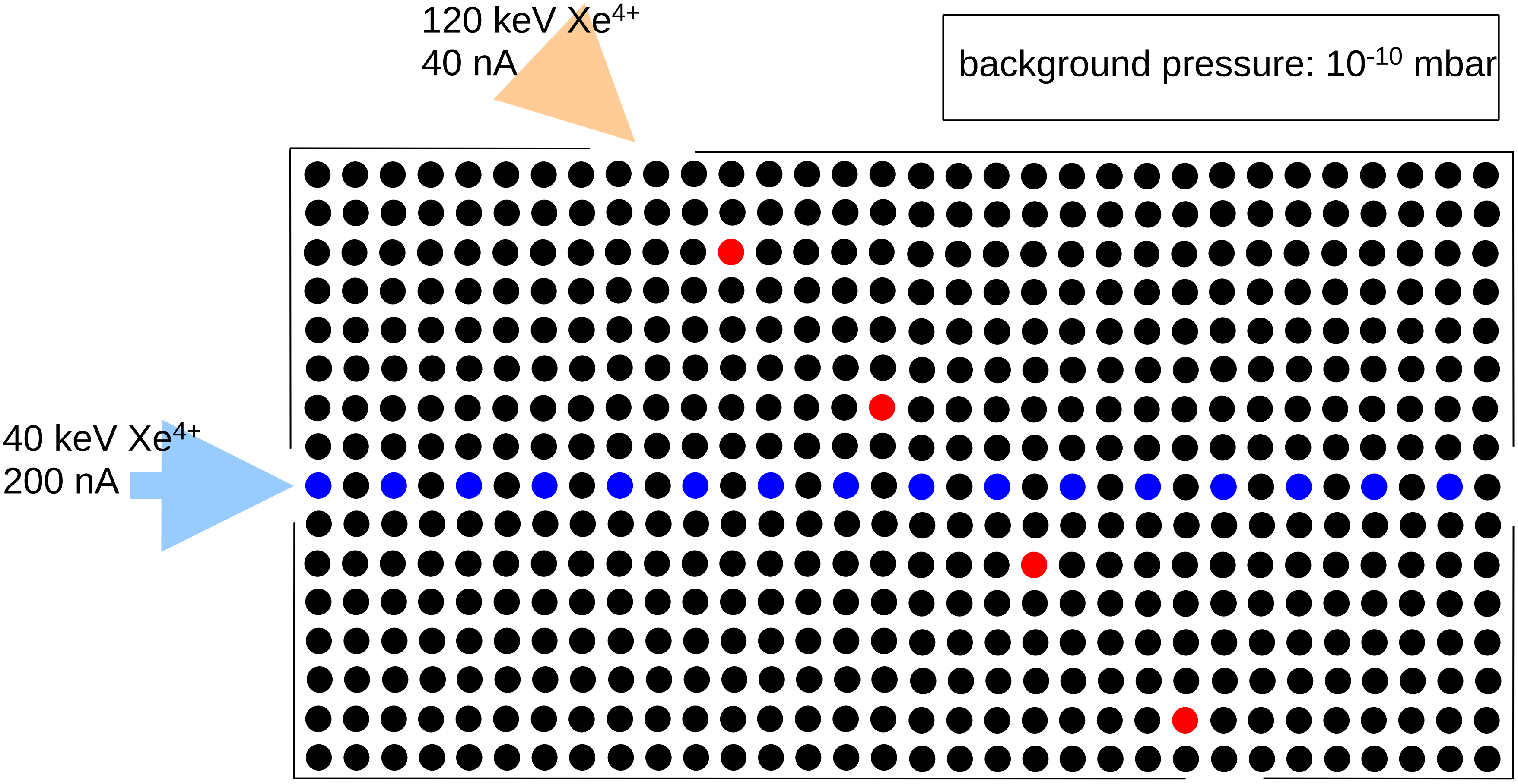
rate coefficient:

total loss cross section:

The Giessen Ion-Ion Experiment



Typical Conditions in a Crossed-Beams Experiment



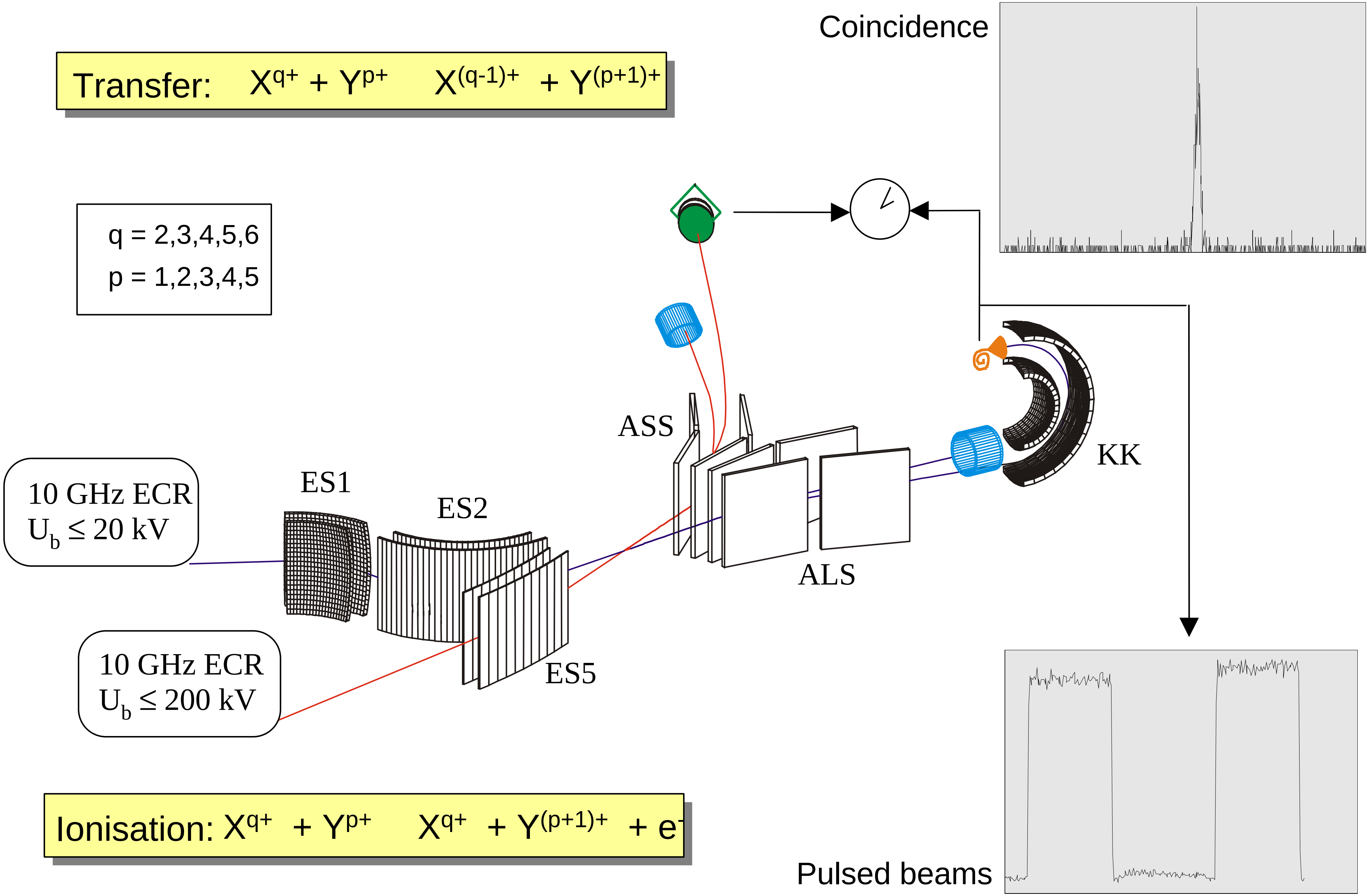
true events:	1 per second
true events / background:	1 : 10^{3}
true events / number of ions:	1 : 10^{13}

Experimental Setup

Transfer: $X^{q+} + Y^{p+} \quad X^{(q-1)+} + Y^{(p+1)+}$

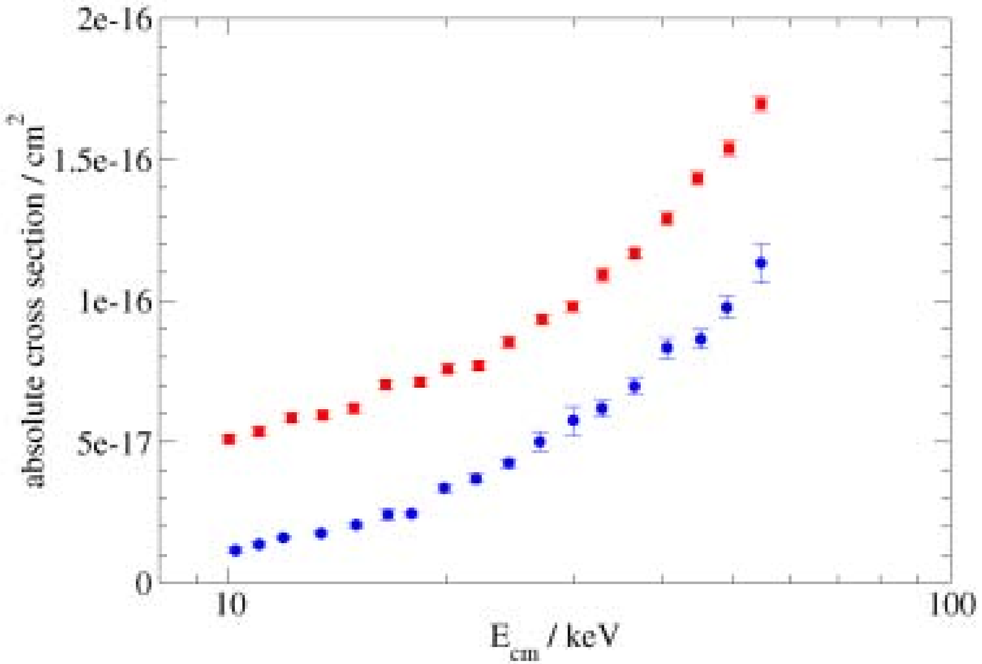
$q = 2,3,4,5,6$

$p = 1,2,3,4,5$



Ionisation: $X^{q+} + Y^{p+} \quad X^{q+} + Y^{(p+1)+} + e^-$

Singly Charged Heavy Ions for HIDIF



charge transfer:

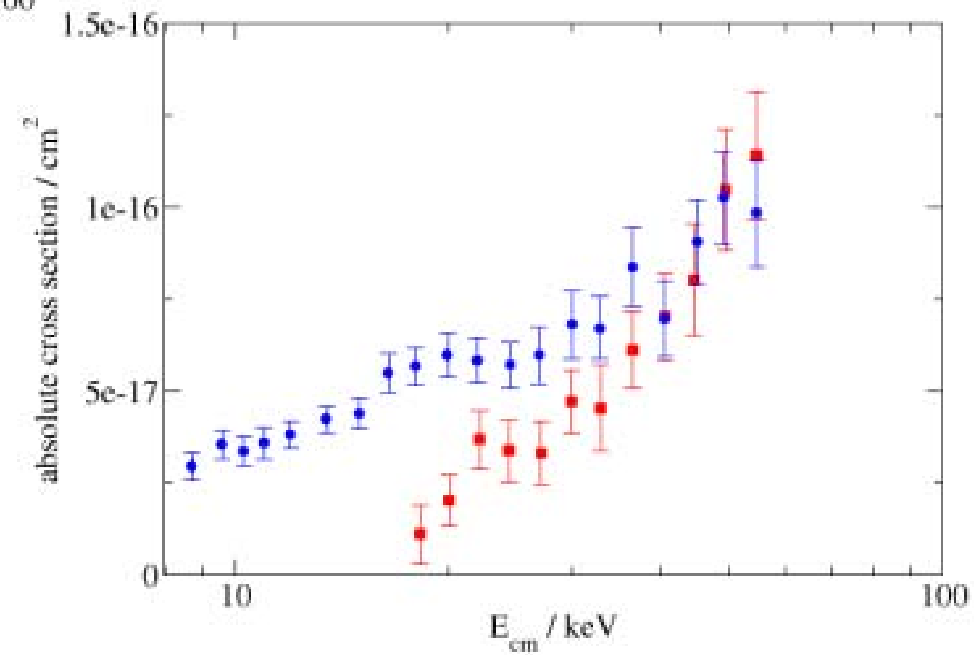
$Xe^+ + Xe^+ \quad Xe^0 + Xe^{2+}$

$Bi^+ + Bi^+ \quad Bi^0 + Bi^{2+}$

ionisation:

$Xe^+ + Xe^+ \quad Xe^+ + Xe^{2+} + e^-$

$Bi^+ + Bi^+ \quad Bi^+ + Bi^{2+} + e^-$

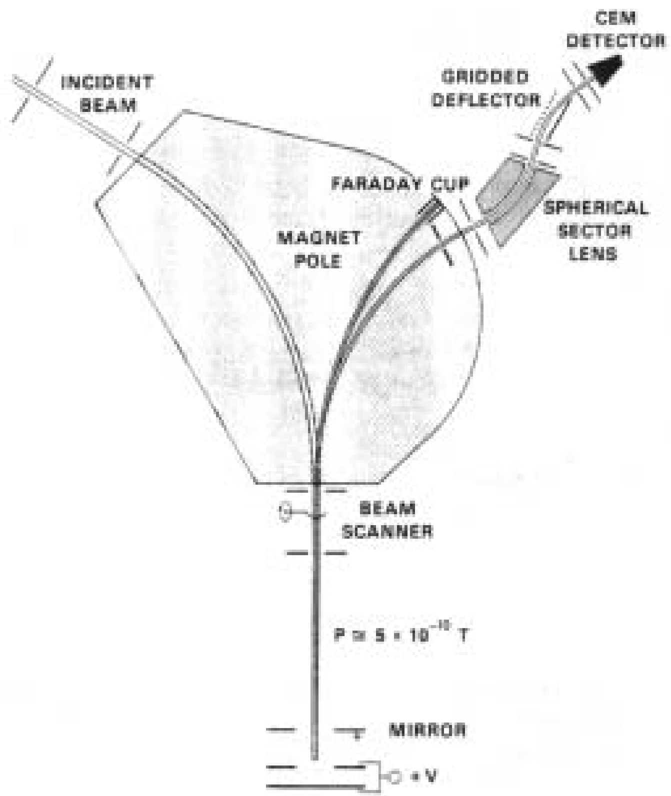


(data from Melchert et al.)

Multiply Charged Heavy Ions

First experiments by Kim&Janev (1987):

- total electron loss only
- single collision energy
- merged beam



Giessen experiments:

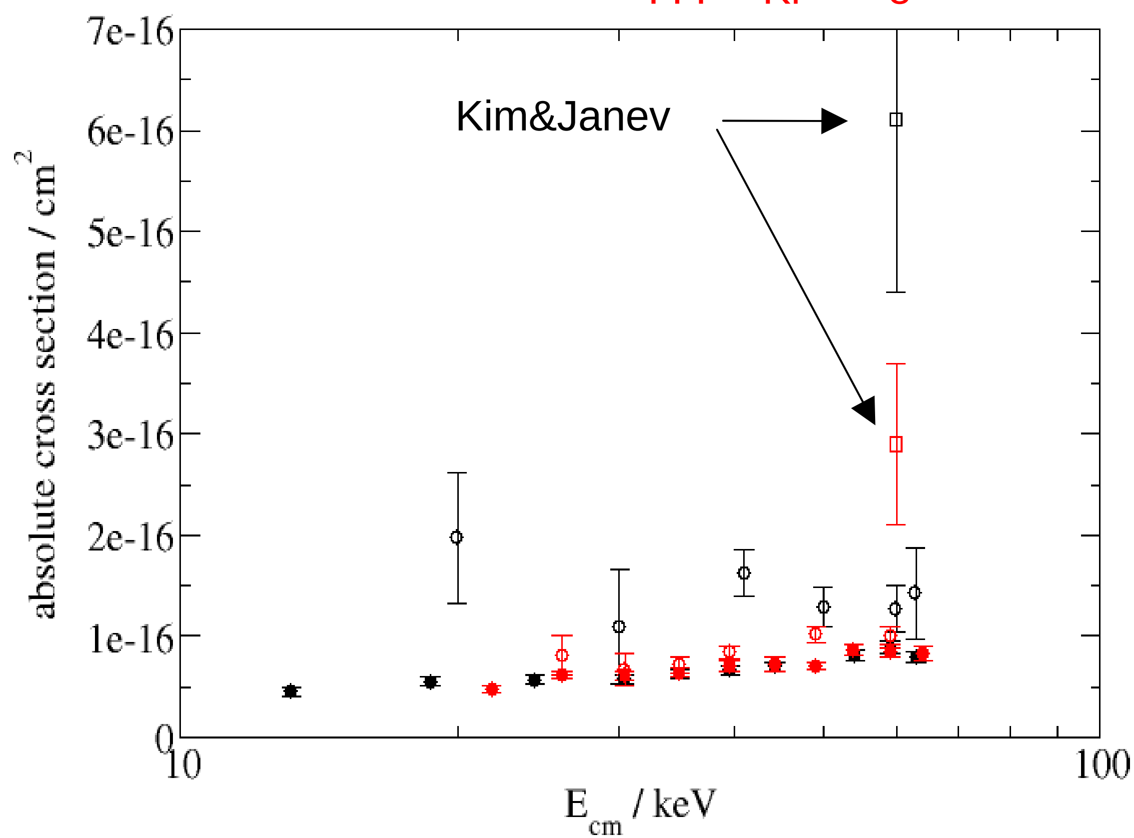
charge transfer and total electron loss:

$Ar^{3+} + Ar^{3+} \quad Ar^{2+} + Ar^{4+}$

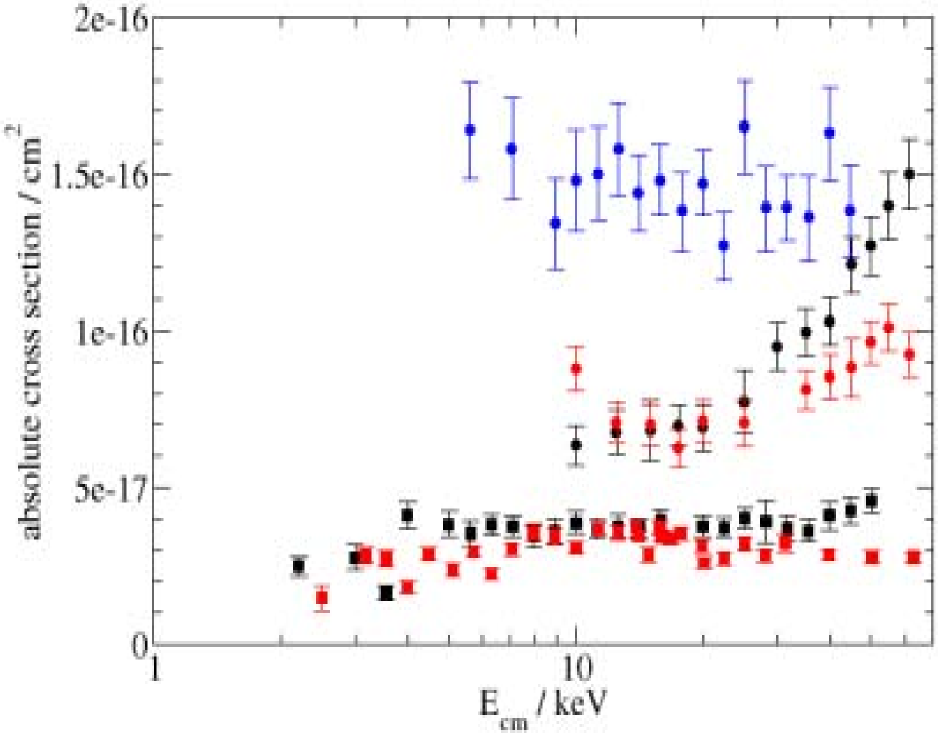
$??? + Ar^{4+} + e^-$

$Kr^{3+} + Kr^{3+} \quad Kr^{2+} + Kr^{4+}$

$??? + Kr^{4+} + e^-$



Multiply Charged Heavy Ions



charge transfer:

$Ar^{4+} + Ar^{4+}$ → $Ar^{3+} + Ar^{5+}$

$Kr^{4+} + Kr^{4+}$ → $Kr^{3+} + Kr^{5+}$

$Xe^{4+} + Xe^{4+}$ → $Xe^{3+} + Xe^{5+}$

$Pb^{4+} + Pb^{4+}$ → $Pb^{3+} + Pb^{5+}$

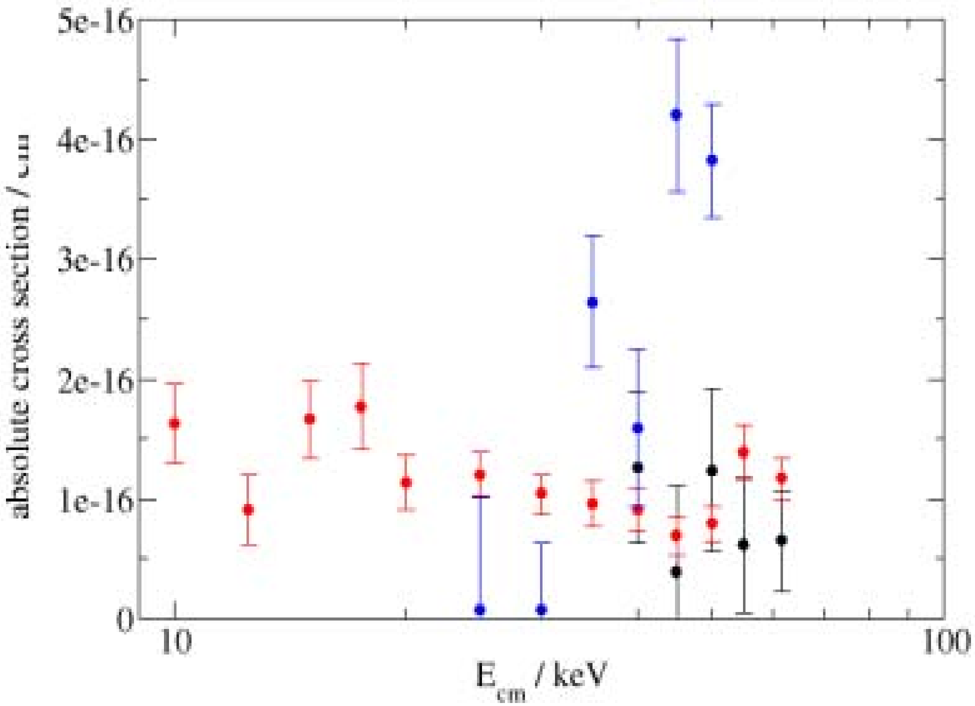
$Bi^{4+} + Bi^{4+}$ → $Bi^{3+} + Bi^{5+}$

ionisation:

$Ar^{4+} + Ar^{4+}$ → $Ar^{4+} + Ar^{5+} + e^-$

$Kr^{4+} + Kr^{4+}$ → $Kr^{4+} + Kr^{5+} + e^-$

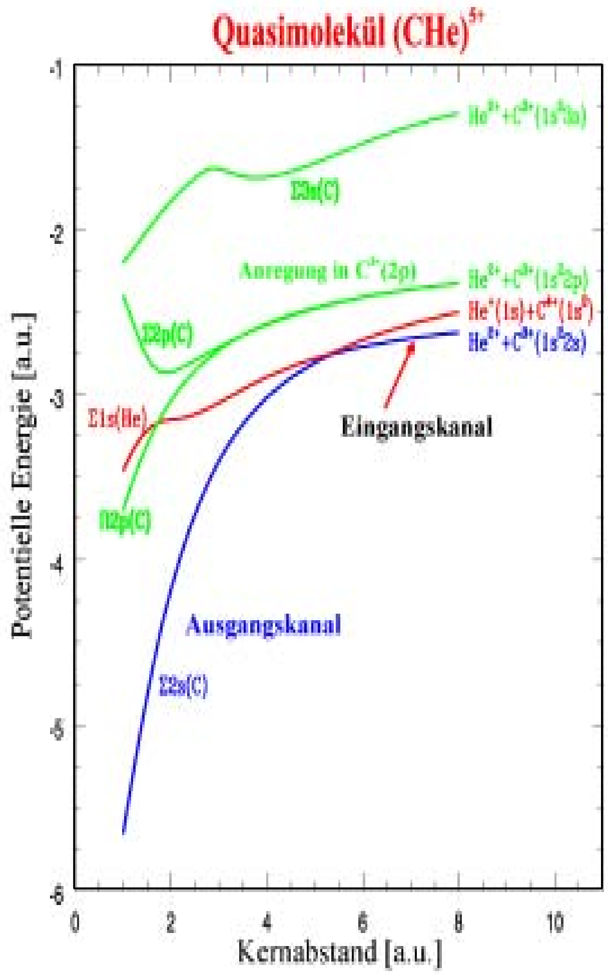
$Xe^{4+} + Xe^{4+}$ → $Xe^{4+} + Xe^{5+} + e^-$



Ionisation cross section can be larger than transfer cross section

Theory ... Where are you ?

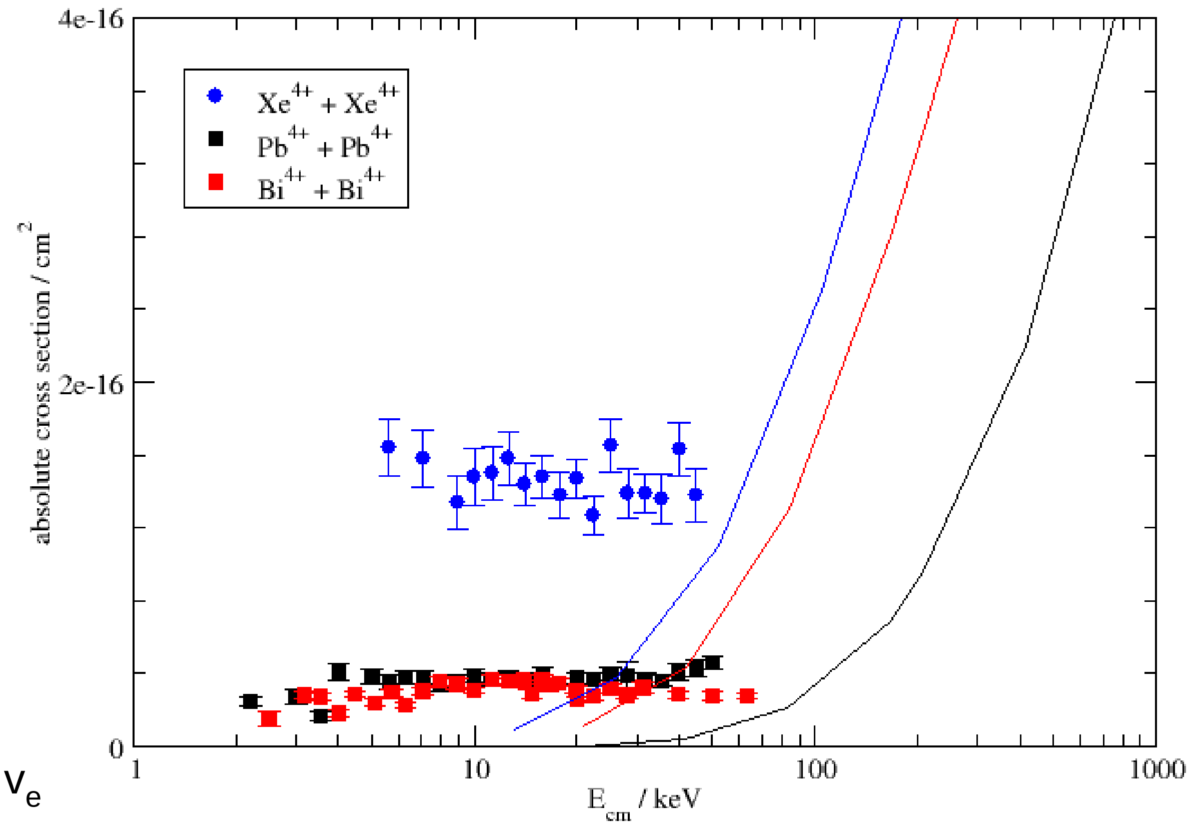
Theoretical calculations exist only for light one- and quasi one-electron systems



Problems with heavy, homonuclear systems:

no perturbation theory applicable: $v_{rel} << v_e$ and $Z_1 = Z_2$

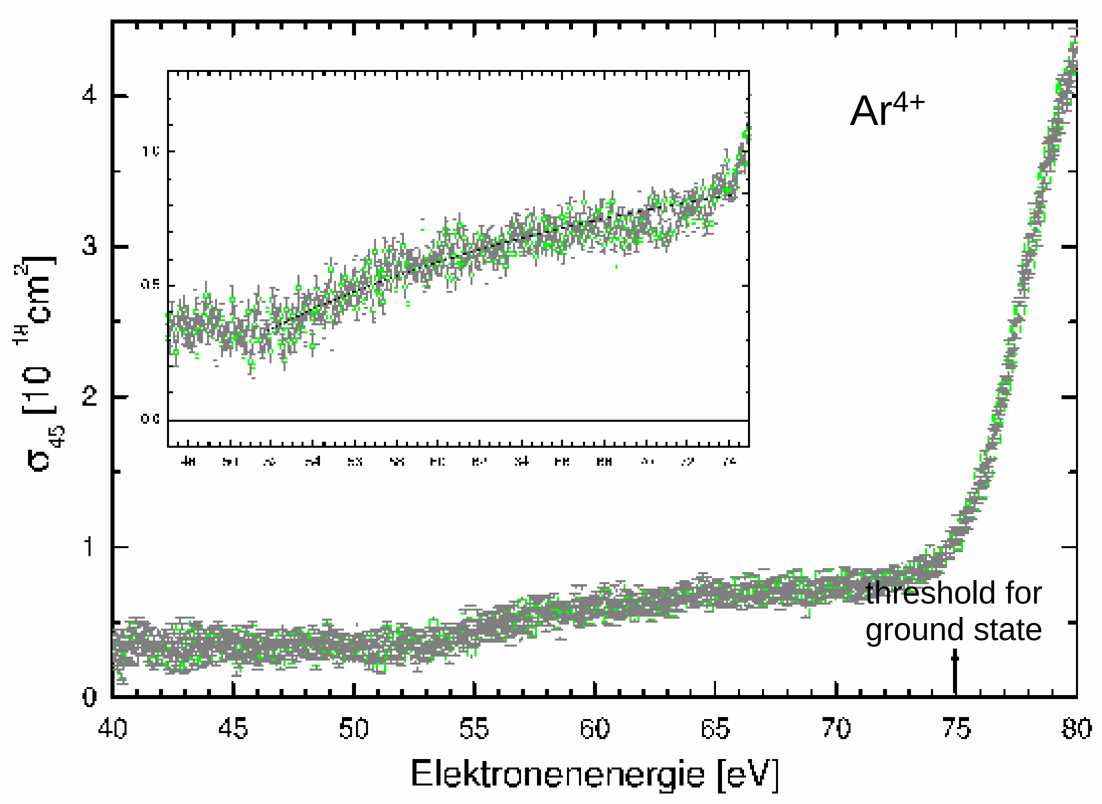
MO-calculations not feasible due to large number of states



Only available calculations for charge transfer are by Shevelko et al. at $v_{rel} \geq v_e$

Metastable Ions

Metastable ions are produced in ECR ion sources



Near threshold electron impact ionisation:

- occupation of all excited states in principle accessible
- no in-situ measurements at the ion-ion experiment feasible yet
- not effective for quenching metastable ions

Ion	I	metastable state	life time	fraction in beam
Ar^{4+}	75eV	$[Ne]3s^2 3p3d\ \ ^3F_4$	0.13s	12%
Kr^{4+}	64eV	probably $[Ar]4s^2 4p4d$	n.a.	18%
Xe^{4+}	54eV	probably $[Kr]5s^2 5p5d$	n.a.	29%

Estimated Intensity Losses

Approximations:

- homogeneous ion density in the beam
- Gaussian velocity distribution
- evaluation of the rate coefficient by Monte-Carlo-simulation (I.Hoffmann, private comm.)

Parameters:

Number of ions: 2×10^{12}

Bunching factor: 0.3

Injection:

$E_{initial}$ = 92 MeV/u

ε_{inital} = 30 mm mrad

Extraction:

E_{final} = 400 MeV/u

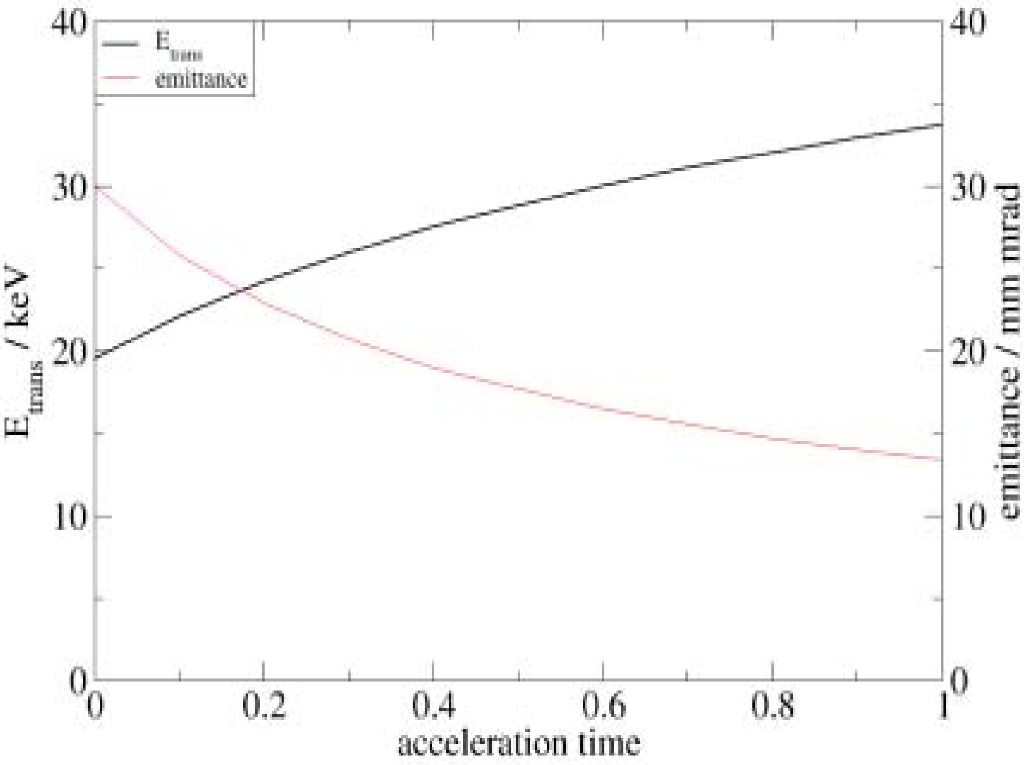
ε_{final} = 14 mm mrad

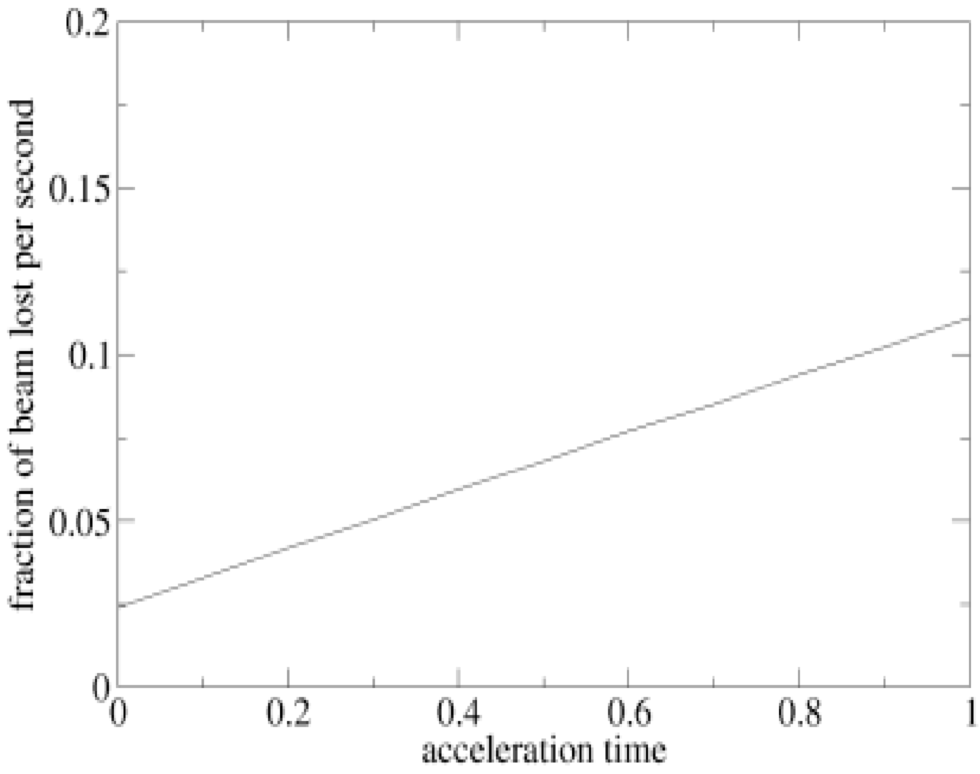
Expected loss based on **charge exchange only**

Ion	Loss without Ionisation	
Ar^{4+}	8.0%	6.8%
Kr^{4+}	6.8%	↑
Xe^{4+}	5.1%	special fit
Pb^{4+}	1.3%	
Bi^{4+}	1.0%	

Estimated Intensity Losses

evolution of beam parameters with acceleration time for an Ar^{4+} beam





Conclusions

Theoretical predictions for charge exchange and/or ionisation are difficult for heavy many-electron systems at low collision velocities !

Future experiments need to:

- investigate systematically charge transfer cross sections in dependence on ion species and charge state
- further investigate the possible influence of ionisation

in order to:

- estimate intensity losses in planned accelerator and storage rings
- find the lowest charge state where charge-changing intra-beam collisions can be neglected

The People

H. Bräuning

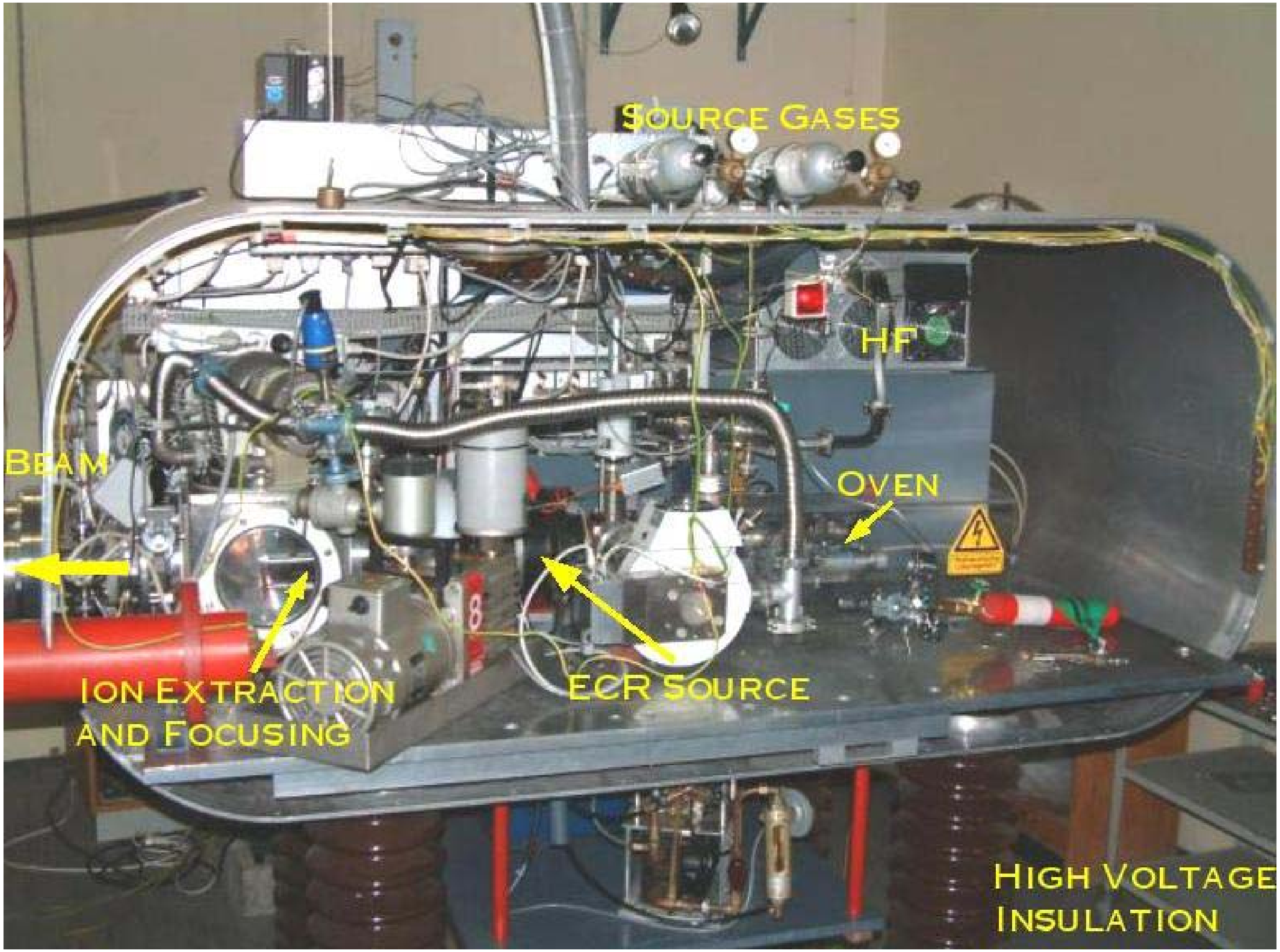
A. Diehl

H. Kern

E. Salzborn

A. Theiß

A. Trassl



in collaboration with I. Hoffmann (GSI)